

Environmental Protection Agency

Critical Flow Orifice Calibration Procedure

This procedure is written for the Environmental Protection Agency, National Vehicle and Fuel Emissions Laboratory (NVFEL) internal use. The use of specific brand names by NVFEL in this procedure are for reference only and are not an endorsement of those products. This document may be used for guidance by other laboratories.

NVFEL Reference Number

210C

Implementation Approval

Original Procedure Authorized by EPCN #102 on 02-03-92

Revision Description

- (1) 09-30-94 The purpose of this change is to revise the procedure as described in EPCN #170.

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1. Purpose

The purpose of this procedure is to calibrate the Critical Flow Orifice (CFO) Kit for verifying Constant Volume Sampler (CVS) performance.

2. Test Article Description

Critical flow orifices are used for propane tracer gas injections.

3. References

- 3.1 "Instruction Manual for the Critical Flow Orifice Kit Model 210;" Horiba Instruments Inc.; November 1978
- 3.2 Letter from Horiba Instruments, Inc., to MSAPC QA Staff, August 1979
- 3.3 "Brooks Vol-U-Meter Operating Instructions," Models 1052 through 1058; Brooks Instrument Division, Emerson Electric Company, 407 West Vine Street, Hatfield, PA 19440, December 1977, Revision A
- 3.4 "Code of Federal Regulations," Title 40, Part 86, Section 86.119
- 3.5 Memo, David L. Munday, November 5, 1991, Subject: "Equations for CFO Calibration"

4. Required Equipment

The following is a list of the equipment used to perform a CFO calibration:

- 4.1 Instrument grade propane
- 4.2 Conoflow single stage regulator; 0-125 lb spring, non-relief type
- 4.3 Shutoff valve

- 4.4 The following components are contained in the CFO kit (see Attachment A):
 - 4.4.1 Precision pressure gauge; 0-100 psig, 8-inch diameter scale or larger, graduated in 0.2-psig increments
 - 4.4.2 Thermometer, 0-120 °F, graduated in 0.5 °F increments
- 4.5 The following components are contained in the Brooks Vol-U-Meter System (see Attachment B):
 - 4.5.1 Brooks Vol-U-Meter Control Box
 - 4.5.2 Valves; 3-way solenoid activated; two required
 - 4.5.3 Connection tubing and large, non-restricting vent and dump lines
 - 4.5.4 Back-pressure manometer; 0-4 inches of water, graduated in 0.5-inch increments
 - 4.5.5 Brooks Vol-U-Meter, Model 1057; 3500-cc capacity (this is known as the Brooks Prover)
- 4.6 Seeka F5 optical sensors; two required
- Note:** One sensor is mounted at the 500-cc mark and the other is mounted at the 2000-cc mark (see Attachment B, Figure 2).
- 4.7 DCI Timer with toggle switch
- 4.8 Mensor Digital Pressure Gauge (central barometer), Model 11900; 0-32 inches of Hg, graduated in 0.001-inch increments.
- 4.9 Vertex Floor Scale, Model 2158; equipped with Toledo Indicators, Model 8146
- Note:** The scale is located in the large soak area.
- 4.10 CFO Kit/Cart Information (see Attachment C)
- 4.11 Form 210-01, "CFO Calibration Data" (see Attachment D)
- 4.12 "CFO Calibration Report" (see Attachment E)
- 4.13 CFO Calibration Program

- 4.14 “MTS CFO Implementation Report” (see Attachment F)

5. Precautions

- 5.1 Cylinders containing compressed gases are used for this procedure. The technician must be familiar with the “Environmental Protection Agency (EPA) Laboratory Safety Manual” sections dealing with the safe handling, storage, and use of compressed gas cylinders.
- 5.2 The gas cylinders and equipment must be checked for leakage, damage, and cleanliness.
- 5.3 Use the Brooks Vol-U-Meter only with approved gases (see the operating manual for details).
- 5.4 Although CFO kits have orifices for use with CO, pure CO should not be used because of its extremely toxic properties. For safety reasons, EPA does not permit CO injections as a routine practice.
- 5.5 The CFO kit must be in the gas lab prior to the start of the calibration for a minimum of 20 minutes to ensure the kit is at room temperature.
- 5.6 After each adjustment is made to the targeted pressure, the flow rate is allowed to stabilize for a minimum of two minutes.
- 5.7 The precision pressure gauge is graduated in 0.2-psig increments but must be read to the nearest 0.1 psig.

6. Visual Inspection

- 6.1 Inspect all fittings with a leak detection fluid when the system is pressurized to 85 psig (see Section 7 for details).
- 6.2 Verify that the CFO kit precision pressure gauge reading is zero when the shutoff valve is closed.
- 6.3 Verify that the Brooks Vol-U-Meter back-pressure manometer reading is zero on the left side of the u-tube when the Control Box is in the “off” position.

If it is not zero, release the set screws on the sliding metal scale and adjust it so the zero mark lines up with the bottom of the meniscus (on the left side).

7. Test Article Preparation

- 7.1 Disconnect the rosette from the cylinder pressure line.
- 7.2 Using the Vertex floor scale, weigh the CFO kit/cart (CFO kit, propane cylinder, and cart). Record the CFO total weight on Form 210-01. The CFO Calibration Program calculates the net weight of the propane in the tank by subtracting the tare weight (displayed on each kit/cart combination) from the total CFO kit/cart weight. See Attachment C for details.

For a valid calibration, the net weight of the propane in the tank must be greater than 25 lb.

If it is not, replace the propane cylinder.

- 7.3 Ensure that the DCI timer and the Brooks Vol-U-Meter Control Box are plugged into an electrical outlet.

If not, plug them in and allow the equipment to warm up for a minimum of two hours.

- 7.4 Push the Brooks Vol-U-Meter Control Box button to the “off” position.
- 7.5 Connect the cylinder pressure line to the Brooks Vol-U-Meter Control Box inlet pressure fitting.
- 7.6 Adjust the regulator to 85 psig and allow the pressure to stabilize for a minimum of two minutes.
- 7.7 Push the Brooks Vol-U-Meter Control Box button to the “flow” position.
- 7.8 Verify that there are no fluctuations in the piston movement and back-pressure manometer reading.
- If fluctuations exist, notify the C&M Manager.
- 7.9 When the piston reaches the top optical sensor, turn the cylinder valve counterclockwise to the “closed” position. The system will now be pressurized.
- 7.10 Inspect all fittings with a leak detection fluid.
- 7.11 Push the Brooks Vol-U-Meter Control Box button to the “off” position.

- 7.12 On Form 210-01, Section A, record all the required data. The previous calibration date and active coefficients are stored in the CFO folder. The CFO folder is stored in the Gas Lab. The cylinder number, purity, and vendor are located on the tank.

8. Test Procedure

A total of 24 data points are collected for a CFO calibration. Each data point consists of a measured supply pressure, within the 60 to 95 psig range, and an elapsed time reading.

The target pressure starts at 60 psig and increases to 95 psig, in 5-psig increments, then decreases from 95 to 60 psig in 5-psig increments.

To provide random confirmation data, the operator then sets 60, 75, 85, 70, 90, 95, 80, and 65 psig.

For each of the target pressures, perform the following steps:

- 100 Turn the cylinder valve clockwise to the “open” position.
- 101 Push the Brooks Vol-U-Meter Control Box button to the “off” position.
- 102 Adjust the regulator to set the supply pressure to within ± 0.4 psi of the target pressure, e.g., 60 psig must be 59.6 - 60.4 psig, 75 psig must be 74.6 - 75.4 psig, etc., for all target data points.
- 103 Allow the set pressure to stabilize for a minimum of two minutes. The stabilized pressure must be within ± 0.4 psig of the target pressure.
- 104 Read the precision pressure gauge to the nearest 0.1 psig.
- 105 On Form 210-01, Section B, record the observed pressure under the column Actual psig.
- 106 When the Brooks Vol-U-Meter piston has descended to the bottom of the chamber, push the DCI toggle switch to the right to stop the timer.

Reset the timer to zero by pushing the toggle switch to the left.

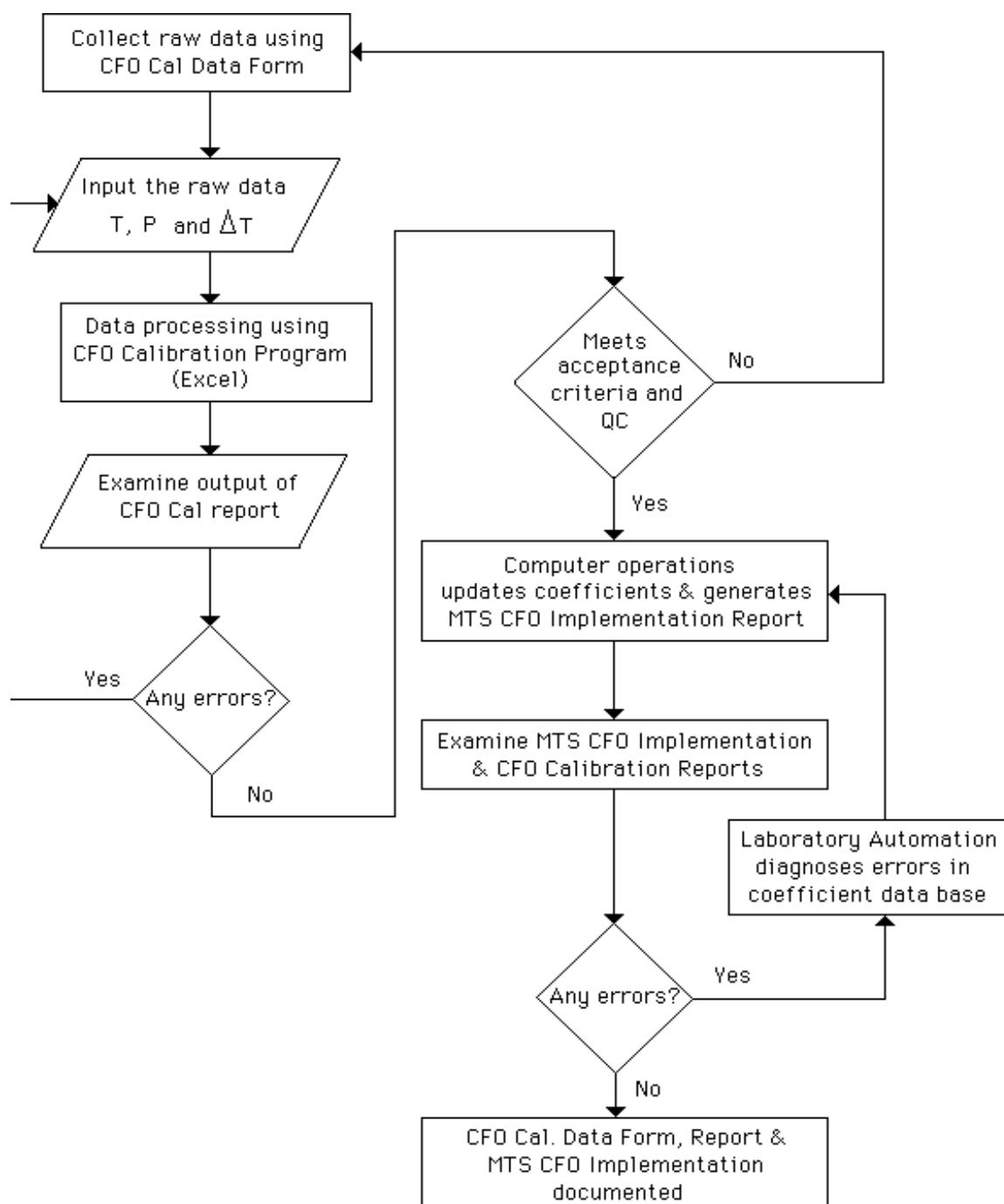
Note: If this is the start of the calibration process, the piston will already be at the bottom of the chamber.

- 107 Push the Brooks Vol-U-Meter Control Box button marked “flow.” This directs the flow into the Brooks Vol-U-Meter, causing the piston to rise.
- 108 Verify that the Brooks Vol-U-Meter back-pressure manometer reading is 1.5 inches of water.
- If it is not, notify the C&M Manager.
- 109 The DCI timer will start when the optical sensor is activated by the top edge of the piston reaching the 500 cc mark on the steel scale.
- 110 Continue to flow the gas until the piston reaches the upper optical sensor (2000-cc mark). The DCI timer will automatically stop when the top edge of the piston reaches this point, thus indicating the elapsed time to flow 1500 cc.
- 111 Push the Brooks Vol-U-Meter Control Box button marked “off.” On Form 210-01, under the column marked “•t seconds, (XX.XXX),” record the elapsed time obtained from the timer readout.
- Note:** The •t must be recorded before the Brooks Vol-U-Meter piston reaches the lower optical sensor (timer automatically resets).
- If the time has not been recorded prior to the piston reaching this point, repeat Steps 102 through 111.
- 112 Repeat Steps 102 through 111 for each of the 24 calibration target pressures listed on Form 210-01 and record the required data. Each target pressure must be set in the order shown on Form 210-01.
- 113 When all of the required data points have been collected, complete Form 210-01, Section C.
- Note:** See the Data Processing Flow Chart.

9. Data Input

- 9.1 The technician opens the CFO Calibration Program (on the C&M MacIntosh computer) and enters the data recorded on Form 210-01.
- 9.2 When all data has been entered, use the scroll bar and move the screen view to the right and preview the “CFO Calibration Report.”

Data Processing Flow Chart



- 9.3 The technician verifies that the “CFO Calibration Report” does not contain any acceptance criteria flags.

If flags appear, see Section 12 for corrective action.

- 9.4 The technician saves the file by pressing the “Save Report” button. This will automatically save the data to the CFO Calibration folder on the hard drive and assign the file name as “CFO Cal Kit # NNNNN MM/DD/YY.”

The NNNNN will contain the kit number, and the MM/DD/YY will have the date that the data were entered into the computer.

- 9.5 The technician then prints the “CFO Calibration Report” by clicking on the “Print Report” button.

- 9.6 A technician, other than the one performing the CFO calibration, verifies that the data in the “CFO Calibration Report” and Form 210-01 are the same.

If no corrections are needed, the technician signs and dates the “CFO Verification Report.” The report is taken to the C&M Manager.

If corrections are needed, they are identified on the report and it is returned for corrective action to the technician who performed the CFO calibration. The technician makes the corrections and repeats Steps 9.1 through 9.5.

- 9.7 The C&M Manager then signs and dates the “CFO Calibration Report,” indicating that the coefficients can be updated on MTS.

- 9.8 The technician inserts a blank 4-inch floppy diskette into the MacIntosh drive. He/She opens the CFO Calibration folder and copies the file named 1011D-CFOCAL onto the floppy.

- 9.9 At the computer input/output window, the technician completes a job request form.

He/She then places the job request form, the 4-inch floppy diskette (with the electronic copy of the 1011D-CFOCAL file), and the signed paper copy of the “CFO Calibration Report” into an envelope. The envelope is then placed in the input basket.

Computer operations will check that the C&M Manager has signed the report before implementing the MTS coefficients. Implementation of the new coefficients on MTS makes them available to the Tracer Gas Injection Program (1011S-TGI).

- 9.10 Computer operations will generate an MTS CFO Implementation Report (see attached sample) containing the following information:

Kit #

Coefficients A, B, and C

Entered By

Implementation Date

- 9.11 The envelope containing the 4-inch floppy diskette and paper copies of the “CFO Calibration Report” and the “MTS CFO Implementation Report” are placed in the output basket where they can be picked up by the technician.

- 9.12 The technician verifies that the data in the “CFO Calibration Report” and “MTS CFO Implementation Report” are the same.

If no corrections are needed, the technician signs and dates the “CFO Calibration Report.”

If corrections are needed, they are identified on the “MTS CFO Implementation Report” and it is taken to the Laboratory Automation Group for corrective action.

- 9.13 When Steps 9.1 through 9.12 have been completed, the technician opens the CFO Calibration Program and pushes the “Update Data Base” button.

This will update the CFO calibration data file named “1011D-CFOCAL” with the new coefficients.

10. Data Analysis

- 10.1 The “CFO Calibration Report” is examined for acceptance criteria flags.

If flags appear, see Section 12 for corrective action.

- 10.2 The data in the “CFO Calibration Report” and Form 210-01 are compared independently by two technicians.

- 10.3 The “CFO Calibration Report” is reviewed and signed by the C&M Manager authorizing that the coefficients can be updated on MTS.

- 10.4 The technician that did compares data in the “CFO Calibration Report” and “MTS CFO Implementation Report” to ensure that they are the same.

If no corrections are needed, the technician signs and dates the CFO Calibration Report.

11. Data Output

- 11.1 The “CFO Calibration Report,” “MTS CFO Implementation Report,” and Form 210-01 are filed in the C&M CFO folder.
- 11.2 The technician notifies the C&M midnight shift that the CFO kit has been calibrated and is ready for use.

12. Acceptance Criteria

The data must meet the following six criteria to be valid; a flag will be displayed on the “CFO Calibration Report” if the data do not meet the criteria.

- 12.1 The net weight of propane in the tank must be greater than 25 lb. prior to the start of the calibration.

If not, Flag #1 appears on the spreadsheet and the calibration is void. Replace the propane cylinder, return to Section 7, complete a new Form 210-01, and repeat the calibration procedure.

- 12.2 The difference between the start and end back-pressure readings must be 0.0 inches H₂O (a reading other than zero indicates friction in the Vol-U-Meter tube).

If it is not zero, Flag #2 appears on the spreadsheet and the calibration is void. Notify the C&M Manager, return to Section 7, complete a new Form 210-01, and repeat the calibration procedure.

- 12.3 The difference between the start and end barometric pressure readings must be less than or equal to 0.12 inches Hg.

If not, Flag #3 appears on the spreadsheet and the calibration is void. Return to Section 7, complete a new Form 210-01, and repeat the calibration procedure.

If after a second calibration attempt the data are not within this limit, notify the C&M Manager.

- 12.4 The difference between the start and end CFO kit thermometer temperature readings must be less than or equal to 2.0 °F.

If not, Flag #4 appears on the spreadsheet and the calibration is void. Allow the kit temperature to stabilize for a minimum of two hours, return to Section 7, complete a new Form 210-01, and repeat the calibration procedure.

If after a second calibration attempt the data are not within this limit, notify the C&M Manager.

- 12.5 The percent of point deviation from the best fit curve must be within $\pm 0.3\%$.

If not, Flag #5 appears on the spreadsheet and the out-of-tolerance data points (actual psig and \bullet t seconds) may be rerun one more time. Cross out the bad data with a single line and initial the area. Open the CFO Calibration Program and make the necessary changes. If the flag persists, the calibration is void.

12.5.1 Clean the CFO kit ruby orifice fitting in a sonic bath.

12.5.2 Return to Section 7, complete a new Form 210-01, and complete the calibration procedure.

12.5.3 If after a second complete calibration attempt the data are not within the specified tolerance, replace the ruby. Return to Section 7, complete a new Form 210-01, and complete the calibration procedure.

- 12.6 The previous calibration date entered into the computer must match the previous calibration date stored in the data base.

If not, Flag #6 appears on the spreadsheet indicating that the coefficients are inactive. Look up the previous calibration date in the CFO folder and verify that the correct date has been recorded on Form 210-01.

If the calibration date is recorded correctly, a computer problem may exist or a report may be missing in the CFO folder; notify the C&M Manager.

13. Quality Control Provisions

- 13.1 Prior to collecting the data all fittings that where connected are inspected with a leak detection fluid.

- 13.2 The CFO kit precision pressure gauge is verified to read zero when the shutoff valve is closed.
- 13.3 The Brooks Vol-U-Meter back-pressure manometer is verified to be reading zero (for the left side of the u-tube) when the Control Box is in the “off” position and the piston is at rest on the bottom.
- 13.4 If the DCI timer and the Brooks Vol-U-Meter Control Box are not plugged in, they are allowed to warm up for a minimum of two hours.
- 13.5 The piston movement and back-pressure manometer reading are verified to ensure that there are no fluctuations.
- 13.6 The flow rate is allowed to stabilize for a minimum of two minutes after each adjustment.
- 13.7 The net weight of the propane in the tank must be greater than 25 lb.
- 13.8 The CFO kit temperature is allowed to stabilize for 20 minutes prior to performing the calibration.
- 13.9 When the piston is moving, the back-pressure manometer must read 1.5 inches of water.
- 13.10 Actual pressure must be within ± 0.4 psig of the target pressure.

Attachment A

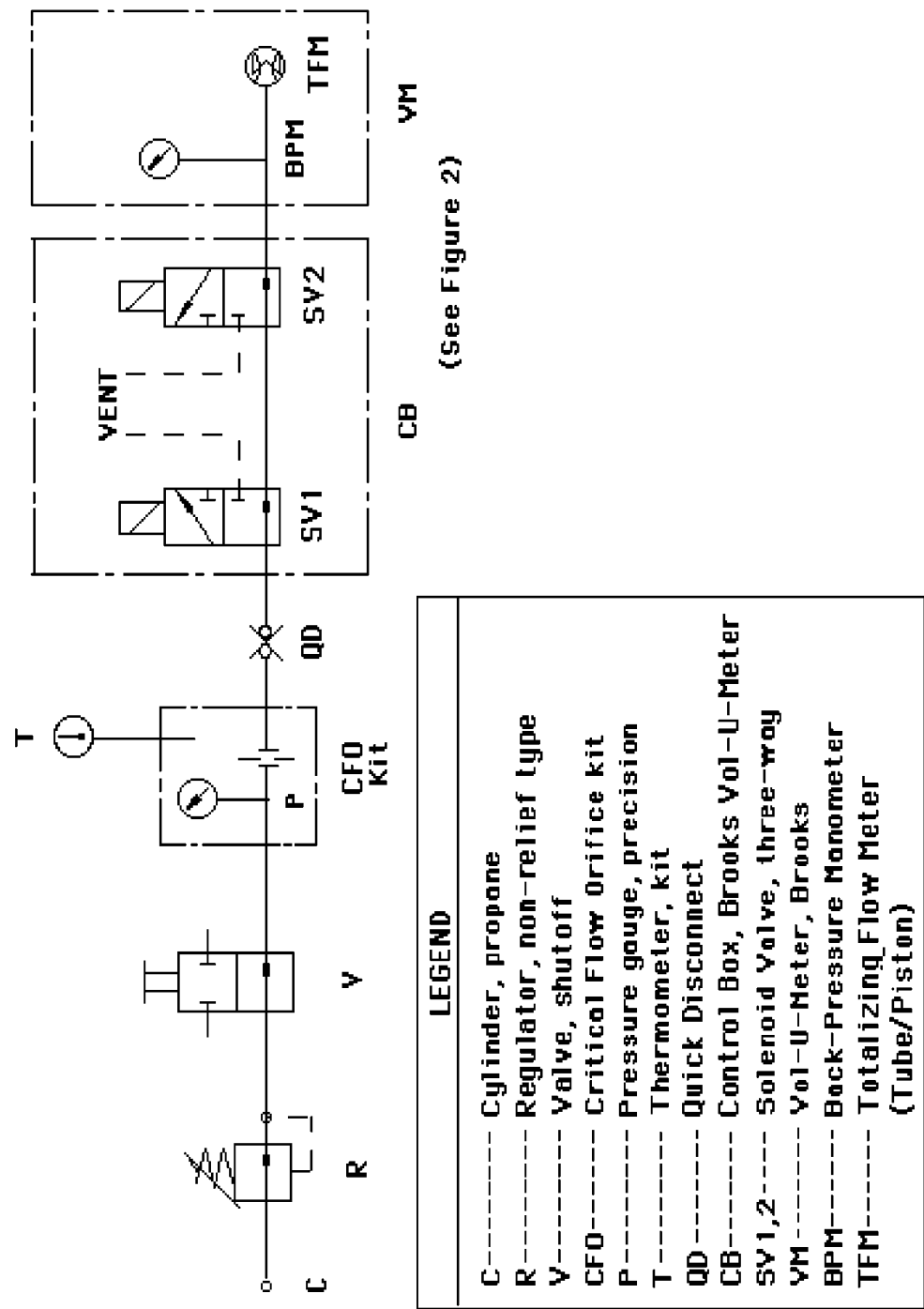


Figure 1 CFD Calibration Schematic

Attachment B

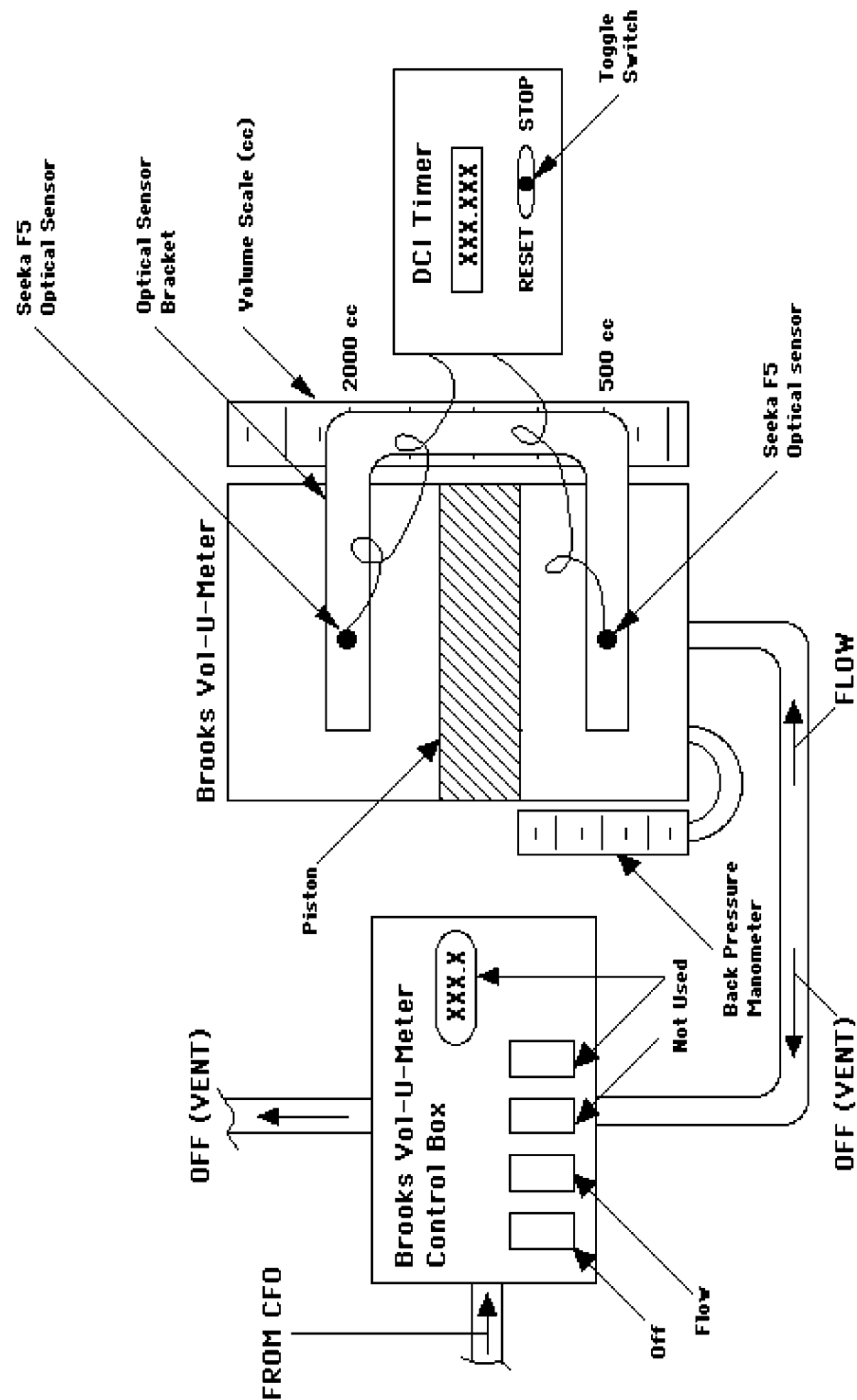


Figure 2 Brooks Vol-U-Meter, Control Box and DCI Timer

Attachment C**CFO Kit/Cart Information**

The propane weight is determined by subtracting the CFO kit/cart tare weight, displayed on each kit/cart combination, from the CFO kit/cart total weight. The propane weight must be greater than 25 lb. for a valid calibration.

The following items contribute to the CFO kit/cart total weight:

1. CFO kit
2. Propane cylinder with valve, regulator, and propane gas
3. Portable cart

The following items contribute to the CFO kit/cart tare weight:

1. CFO kit
2. Empty propane cylinder with valve and regulator
3. Portable cart

Listed below are the tare weights of the CFO kits currently in use. Note that the CFO tare weights differ from kit to kit.

Kit Number	Empty Propane Cylinder (lb)	CFO Kit/Cart (lb)	Tare Weight (lb)
038625	95	183	278
086942	95	180	275
181102	95	150	245
181103	95	150	245
106380	95	182	277

Attachment D
CFO Calibration Data

Section A: Technician's Name: _____ Cylinder #: _____
 CFO Kit Number: _____ Cylinder Vendor: _____
 Current Date: _____ Cylinder Purity: _____
 Date of Previous Calibration: _____ CFO Total Weight: _____ lb
 Calibration Start Time: _____ Start Back Pressure: _____ inches H₂O
 Start CFO Kit Thermometer Temp: _____ °F Start Barometer: _____ inches Hg


Section B: Collect 24 calibration points in the order listed below.

Target psig	Actual psig, (XX.X)	• t seconds, (XX.XXX)
(1) 60	(1) _____	(1) _____
(2) 65	(2) _____	(2) _____
(3) 70	(3) _____	(3) _____
(4) 75	(4) _____	(4) _____
(5) 80	(5) _____	(5) _____
(6) 85	(6) _____	(6) _____
(7) 90	(7) _____	(7) _____
(8) 95	(8) _____	(8) _____
(9) 95	(9) _____	(9) _____
(10) 90	(10) _____	(10) _____
(11) 85	(11) _____	(11) _____
(12) 80	(12) _____	(12) _____
(13) 75	(13) _____	(13) _____
(14) 70	(14) _____	(14) _____
(15) 65	(15) _____	(15) _____
(16) 60	(16) _____	(16) _____
(17) 60	(17) _____	(17) _____
(18) 75	(18) _____	(18) _____
(19) 85	(19) _____	(19) _____
(20) 70	(20) _____	(20) _____
(21) 90	(21) _____	(21) _____
(22) 95	(22) _____	(22) _____
(23) 80	(23) _____	(23) _____
(24) 65	(24) _____	(24) _____

Section C:

Calibration End Time: _____ End Back Pressure: _____ inches H₂O
 End CFO Kit Thermometer Temp: _____ °F End Barometer: _____ inches Hg
 Ruby Cleaned _____ YES _____ NO Ruby Replaced _____ YES _____ NO
 Comments: _____

Attachment E

CFO Kit No: 106380										CFO Calibration Report										Process: Jan-30-1992 13:34																			
CFO Kit Number		Technician Name		Cylinder Number		Cylinder Purity		Cylinder Vendor		CFO Total Wght (lbs)		Date of Previous Calibration		Current Date																									
106380		Parker		RC3864		99.50%		Liquid Carbonic		300		8/1/91		11/8/91																									
		Back Pressure (H2O)		Barom. Pressure (Hg)		Kit Temp °C		Cal. Time		Delta Vol (cc)		CFO Tare Weight (lbs)		Coefficients		New Coefficients																							
		START		1.5		2026		75.5				A =		256113E-06																									
		END		1.6		2020		74.5				B =		744287E-03																									
		AVG.		1.6		2023		75.0				C =		-133618E-02																									
		Range		-0.1		0.06		1.0				RUBB		YES/NO																									
Flags		# 2								23		CLEANED		No		REPLACED		No																					
		FLAG								# 1																													
#	Actual PSIG	Delta t (SECS)	$\frac{P_s - P_a}{T_s - T_a}$	$\frac{P_s - P_a}{T_s - T_a} + B \cdot P_a + C$	% Diff	Flags	#	Actual PSIG	Delta t (SECS)	$\frac{P_s - P_a}{T_s - T_a}$	$\frac{P_s - P_a}{T_s - T_a} + B \cdot P_a + C$	% Diff	Flags																										
1	600	134.061	0.530202	0.530666	-0.08%		1	60	134.061	0.530202	0.530666	-0.08%																											
2	650	124.454	0.571227	0.571006	0.04%		16	60	133.654	0.531112	0.530666	0.08%																											
3	700	117.014	0.610871	0.610871	-0.54%	# 5	17	60	13																														

Attachment F

MTS CFO Implementation Report

Kit :

New Coefficients:

A=

B=

C=

Entered By:

Implementation Date: